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Single-chain antibodies against the 37 kDa/67 kDa laminin receptor as tools for the diagnosis and therapy of prion diseases and cancer, production and use thereof

The present invention lies in the field of antibodies which are directed against the cell surface receptor of prion proteins, the 37 kDa/67 kDa laminin receptor. In particular, the present invention relates to single-chain antibodies which specifically recognize both the 37 kDa precursor form of the laminin receptor (37 kDa LRP) and the 67 kDa high-affinity form of the laminin receptor (67 kDa LR).

Prion proteins, which are involved in the occurrence of very different forms of transferable spongiform encephalopathies (TSEs), such as scrapie in sheep, mice and hamsters, transferable spongiform encephalopathy of cattle (BSE), transferable spongiform encephalopathy in mink (TME), kuru, Gerstmann-Sträußler-Scheinker syndrome (GSS), Creutzfeldt-Jakob disease (CJD) and fatal familial insomnia (FFI) in man, consist mainly, even if not entirely, of PrP^{Sc}, an anomalous isoform of the ubiquitous cellular prion protein PrP^{c} (see, for example, Aguzzi and Weissmann, 1998; Lasmézas and Weiss, 2000; Prusiner et al., 1998).

It is known from WO 98/53838 and from Rieger et al. (Rieger et al., 1997) that the PrP^{c} binds specifically to the cell surface receptor of prion proteins, the 37 kDa LRP/67 kDa LR. It is known from WO 98/53838 and from EP-A-1 127 894 and from Rieger et al. (Rieger et al., 1997) that the laminin receptor level in tissues of animals infected with scrapie, such as hamsters and mice, is increased.

Gauczynski et al., 2001b show that the 37 kDa LRP/67 kDa LR functions as a receptor for PrP^{c}. Binding sites on both molecules have been mapped (Hundt et al., 2001) and heparan sulfate proteoglycans (HSPGs) identified as cofactors or coreceptors for PrP^{c} (Hundt et al., 2001).

The 37 kDa *laminin receptor precursor* (37 kDa LRP, p40, LBP) is the precursor protein of the 67 kDa *high affinity* laminin receptor (67 kDa LR) (Rao et al., 1989; Yow et al., 1988).

The 67 kDa form was initially isolated from tumor cells (Lesot et al., 1983; Malinoff and Wicha, 1983; Rao et al., 1983), where the protein has a high affinity to laminin.

The 37 kDa/67 kDa laminin receptor is furthermore overexpressed in tumor tissues (Lesot et al., 1983; Malinoff and Wicha 1983; Rao et al., 1983).

Laminin is a glycoprotein of the extracellular matrix, where it is involved in the adhesion, motion, differentiation and growth of cells (Beck et al., 1990). Both forms of the laminin receptor exist together in mammalian cells, which it was possible to show by immunological studies of membrane fractions (Gauczynski et al., 2001b).

The 37 kDa form also occurs in the cytosol, where it is associated with ribosomes and can take over tasks in protein translation (Auth and Brawermann, 1992; Sato et al., 1999). The existence of this protein in the nucleus was also discussed, where it should also be involved in the maintenance of structures (Kinoshita et al., 1998; Sato et al., 1996).

LRP/LR is a multifunctional protein which, starting from the gene product p40, can form two different forms, occurs in various cell compartments and exerts different functions there. The amino acid sequence of the 37 kDa/67 kDa laminin receptor is highly conserved, with a high homology in mammals (Rao et al., 1989). By means of an evolution analysis of the amino acid sequence, it was possible to show that the palindromic sequence LMWWML is responsible for the ability to bind laminin. This sequence lies in the PrP-binding region of the 37 kDa LRP (Ardini et al., 1998; Hundt et al., 2001; Rieger et al., 1997).

It appears that the ribosomal protein p40, which initially did not possess the ability to bind laminin (Auth and Brawerman, 1992), evolved in the course of evolution by amino acid exchange and introduction of post-translational changes to a laminin-binding cell surface protein which can also bind elastin (Hinek et al., 1988; Salas et al., 1992) and carbohydrate chains (see, for example, Ardini et al., 1998; Mecham, 1991; Rieger et al., 1999).

The laminin receptor family is highly conserved in many eukaryotic cells (Keppel and Schaller, 1991; Wewer et al., 1986) and can also be found in *Archaea* (Ouzonis et al., 1995).

The 37 kDa LRP functions as a receptor for the Venezuelan equine encephalitis virus on mosquito cells (Ludwig et al., 1996), while the 67 kDa form can obviously be used as a receptor for the Sindbis virus (Wang et al., 1992).

With respect to the processes underlying the conversion of the 37 kDa form to the 67 kDa protein, it is known that both proteins consist of the 37 kDa component, a number of proposals having been made to explain the greater mass of the mature protein. Homodimerization of the 37 kDa protein and also binding to another component have been discussed (Castronovo et al., 1991; Landowski et al., 1995). Other studies, however, propose a heterodimer stabilized by fatty acids (Buto et al., 1998). It has recently been shown that the 67 kDa laminin receptor also occurs on activated human T lymphocytes and has a strong affinity there, together with integrins, to laminin (Canfield and Khakoo, 1999).

It is to be emphasized, however, that currently the 37 kDa/67 kDa polymorphism is not conclusively explained.

The 37 kDa/67 kDa laminin receptor is represented by a number of genes in the genome of mammals. In man, there are 26, in the mouse 6, copies (Fernandez et al., 1991; Jackers et al., 1996b). The gene consists of seven exons and six introns, most gene copies probably being pseudogenes (Jackers et al., 1996a). In the mouse, there are hints that at least two of the six genes are active and situated on chromosome 9 (Douville and Carbonetto, 1992; Fernandez et al., 1991). With the aid of TRIBE-MCL, an algorithm for the detection of protein families (Enright et al., 2002), five LRP genes were identified when using the program for the screening of the relevant mouse genome sequence data bank (www.ensembl.org). Interestingly, it was recently shown that on chromosome 9 are possibly situated gene loci which influence the incubation time of prion diseases in mice (Stephenson et al., 2000).

The gene which codes for the 37 kDa LRP has been identified in many different species, such as *Saccharomyces cerivisiae* (Davis et al., 1992), *Arabidopsis thaliana* (Garcia-Hernandez et al., 1994), *Drosophila melanogaster* (Melnick et al., 1993), the sea urchin *Urechis caupo* (Rosenthal and Wordeman, 1995), *Chlorohydra veridissima* (Keppel and Schaller, 1991), *Candida albicans* (Lopez-Ribot et al., 1994) and the Archaebacterium *Haloarcula*

marismortui (Ouzonis et al., 1995) and the mammals (see, for example, Gauczynski et al., 2001a; Leucht and Weiss, 2002; Rieger et al., 1999).

It is known from WO 98/53838 and from a later publication (Leucht et al., 2003) that the polyclonal LRP antibody W3 prevents PrP^{Sc} replication in cultured neuronal cells. Generally, this shows that antibodies against 37 kDa LRP/67 kDa LR can completely suppress prion replication at least in cell culture. Interestingly, the cells also then remained free of PrP^{Sc} (Leucht et al., 2003) if, after further culturing for a further two weeks, no LRP/LR antibody was added. Generally, this shows that LRP/LR antibodies are able to completely cure prion-infected cell cultures of a prion infection.

Furthermore, it is known from EP-A-1 127 894 that LRP/LR antibodies can be employed diagnostically for the recognition of prion diseases, since the LRP/LR level is increased in tissues of rodents infected with scrapie.

Polyclonal antibodies against LRP/LR, which are described in WO 98/53838 and EP-A-1 127 894, possess the disadvantage, however, that they can only be selected with difficulty, are very large and exhibit high immunogenicity. In contrast to single-chain antibodies, which can be synthesized in large amounts in E. coli, these antibodies are only available to a restricted extent.

It was consequently the object of the present invention to make available novel monoclonal antibodies which specifically recognize LRP/LR, which are easy to select, are distinguished by a small size and have low immunogenicity.

The subject of a first aspect of the present invention is a single-chain antibody molecule, which is directed specifically against LRP/LR and which comprises the amino acid sequence SEQ ID No. 2, and homologs or fragments thereof, and homologs of the fragments.

The subject of a further aspect of the present invention is a single-chain antibody molecule, which is directed specifically against LRP/LR and which comprises the amino acid sequence SEQ ID No. 4, and homologs or fragments thereof, and homologs of the fragments.

A homolog of the antibody molecule which comprises the amino acid sequence SEQ ID No. 2 or 4 is customarily homologous to at least 70%, preferably to 80 or 90% and in particular to 95%, to the antibody molecule comprising the amino acid sequence SEQ ID No. 2 or 4 over a region of at least 60, 80 or 100 or more adjacent amino acids.

In general, a fragment of the antibody molecule according to the invention which comprises the amino acid sequence SEQ ID No. 2 or 4, or a homolog thereof, has an amino acid length of at least 30, 40, 50 or 60 amino acids.

The subject of a further aspect of the present invention is a cDNA which codes for the antibody molecule having the designation S18, which is directed against LRP/LR and which comprises the nucleotide sequence SEQ ID No. 1, and a fragment cDNA which selectively hybridizes to the cDNA.

The subject of a further aspect of the present invention is a cDNA which codes for the antibody molecule having the designation N3, which is directed against LRP/LR and which comprises the nucleotide sequence SEQ ID No. 3, and a fragment cDNA which selectively hybridizes to the cDNA.

A cDNA having the ability for selective hybridization to the cDNA which comprises the nucleotide sequence SEQ ID No. 1 or 3 is customarily homologous to at least 70%, preferably to 80 or 90% and in particular to 95%, to the cDNA comprising the nucleotide sequence SEQ ID No. 1 or 3 over a region of at least 60, 80 or 100 or more adjacent nucleotides.

The subject of a further aspect of the present invention is a replication or expression vector which carries the cDNA according to the invention. The vectors can, for example, be plasmid, virus or phage vectors which comprise a replication origin and optionally a promoter for the expression of the cDNA and optionally a regulator of the promoter. The vector can contain one or more selectable marker genes, for example the ampicillin resistance gene. The vector can be used in vitro, for example for the production of RNA corresponding to the cDNA, or

for the transfection of a host cell. Suitable vectors are, for example, viral vectors (lentiviruses, adenoviruses, adeno-associated viruses (AAV)).

The subject of a further aspect of the present invention are host cells which are transformed with the vectors for the replication and expression of the cDNA according to the invention, including the cDNA which comprises the nucleotide sequence SEQ ID No. 1 or 3 or the open reading frame thereof. The cells are chosen such that they are compatible with the vector. Examples of these are bacteria, yeast, insect cells or mammalian cells, in particular E. coli cells or mammalian cells.

The subject of a further aspect of the present invention is a process for the production of an antibody molecule, which comprises culturing host cells according to the present invention under conditions effective for the expression of an antibody molecule according to the invention.

The subject of a further aspect of the present invention are pharmaceutical compositions which comprise an antibody molecule according to the invention in combination with a pharmaceutically acceptable diluent and/or vehicle.

In a further preferred embodiment, the abovementioned pharmaceutical composition is suitable for the treatment of prion diseases.

The subject of a further aspect of the present invention are diagnostic compositions which comprise an antibody molecule according to the invention in combination with an acceptable diluent and/or vehicle.

The antibody molecule described above also comprises those in which a part of their amino acid sequence is missing (i.e. an antibody molecule which only comprises the essential sequence for the display of the biological activity of the amino acid sequence indicated in SEQ ID No. 2 or 4), those in which a part of their amino acid sequence is replaced by other amino acids (i.e. in which an amino acid is replaced by an amino acid of similar property) and those in which other amino acids are added to or inserted in a part of their amino acid sequence.

Fig. 1 shows the schematic representation of a single chain (single-chain antibody) scFv in comparison with the antibody having the full length, consisting of a Fab and Fc part. The scFv consists of a part of the heavy chain (V_H) and a part of the light chain (V_L). Both parts originate from the Fab part of an antibody which is responsible for antigen recognition. V_H and V_L are connected by a linker (YOL).

Fig. 2 shows schematically the naive scFv bank which was used for the screening of the scFv antibody directed against GST::LRP. The naive bank contains approximately 2 x 10^9 clones and was generated by the combination of the coding regions for the heavy (V_H) and light (V_L) chains after PCR amplification of the respective cDNA from spleen or PBLs (peripheral blood lymphocytes).

Fig. 3 shows schematically the synthetic scFv bank consisting of selected frameworks having good folding properties and high expression rates and comprising randomized sequences in their CDR3 regions. The bank contains approximately 1 x 10^9 clones.

Fig. 4 shows schematically the screening process by means of phage display. In this process, the naive or synthetic scFv banks shown in Fig. 2 and Fig. 3 are employed. The antigen GST::LRP described in WO 98/53838 was immobilized on polystyrene tubes. Only phages which present scFv which bind GST::LRP are selected. Nonspecifically bound phages are washed off. Amplification of these phages follows, these being enriched by means of three successive selection rounds.

Fig. 5 shows an ELISA of periplasmatic crude extracts of clones obtained after three selection rounds from the naive scFv bank. The extracts were tested on recombinant GST::LRP fusion protein. The result is shown in Fig. 7 in tabular form. K = only secondary antibody.

Fig. 6 shows an ELISA of periplasmatic crude extracts of clones obtained after three selection rounds from the synthetic scFv bank. The extracts were tested on recombinant GST::LRP fusion protein. The result is shown in Fig. 7 in tabular form. K = only secondary antibody.

Fig. 7 compiles the result of the ELISAs from Figs. 5 and 6 schematically. 32 of 48 clones (66%) in the case of the naive bank (Fig. 5) and 25 of 47 clones (53%) from the synthetic bank showed positive signals. Furthermore, retesting of 13 clones from the naive and 6 clones from the synthetic banks on GST (without a fusion partner) was carried out. GST was not recognized, which allows it to be concluded that the scFvs only recognize the LRP part of the fusion protein. A restriction analysis of the cDNAs of the 13 clones from the naive bank with *Bst*NI showed that 10 clones were identical (10/13). A further clone was identified twice (2/13). One clone (N37) showed an individual restriction pattern.

Fig.8 shows the detection of recombinant GST::LRP by individual clones selected from the synthetic (S) and naive (N) scFv banks. Selected clones which were identified by means of ELISA (Figs. 5 and 6) were tested in the Western Blot. In each track, a mixture of rec. GST and GST::LRP expressed in the Baculovirus system was separated on a 12% strength SDS-PA gel. The proteins were blotted on a nitrocellulose membrane. The individual tracks of the blots were cut out and the individual strips were incubated with periplasmatic extracts of the selected individual scFvs from the naive and synthetic banks or respective controls. The polyclonal anti-LRP antiserum W3 known from WO 98/53838 was detected using a polyclonal goat anti-rabbit (hare) HRP conjugate (Dianova). The scFvs were detected using a monoclonal mouse anti-penta-histidine antibody (Qiagen) followed by a goat anti-mouse HRP conjugate (Dianova). Anti-rabbit-HRP: only goat anti-hare conjugate. Anti-His: monoclonal mouse anti-histidine antibody with a further goat anti-mouse HRP conjugate. Anti-mouse HRP: only goat anti-mouse HRP conjugate. MluC5: monoclonal anti-LRP antibody, which does not function in the Western Blot analysis.

The scFvs N3, and S18 and S23 produced strong signals. None of the scFv antibodies recognized rec. GST, which shows that all scFvs recognize the LRP part.

Fig.9 shows the detection of LRP/LR on the surface and intracellularly of N2a cells.

Surface: The cells were incubated with 100 µg/ml of anti-LRP antiserum W3 (WO 98/53838), then with the FITC-conjugated goat anti-hare IgG.

scFv anti-LR/LRP N3 and S18 were employed at in each case 18 µg/ml and detected using monoclonal anti-His antibody (1:20; Dia900) followed by FITC-conjugated goat anti-mouse IgG.

Intracellular: The cells were fixed with 3% paraformaldehyde, and incubated with 50 mM NH_4Cl/20 mM glycine before staining with the antibodies described above with the following modification: all washing and incubation steps were carried out at room temperature in a 0.1% saponin-containing buffer. The scFv antibodies were in each case employed at concentrations to 9 µg/ml.

Fig. 10 shows the detection of LRP/LR on the surface and intracellularly of Jurkat cells (human, peripheral blood leukemia T cells). The antibodies, secondary and tertiary antibodies used correspond to those described in the legend of Fig. 9. The method used corresponds to that described in Fig. 9 apart from the fact that Jurkat cells were used.

Fig. 11 shows the detection of recombinant LRP::FLAG or endogenous LRP/LR in baby hamster kidney cells (BHK) transfected with SFV1-huLRP-FLAG or SFV1-moLRP::FLAG. BHK cells were either not transfected (n.t.) or transfected in the manner known to the person skilled in the art in the specialty with the rec. Semliki forest virus (SFV) RNAs SFV1-huLRP-FLAG or SFV1-moLRP::FLAG. The method of preparation of rec. SFV RNA, the transfection and the analysis by Western Blotting or immunofluorescence (Fig.12) or FACS (Fig.13) have already been described (Gauczynski et al., 2002; Gauczynski et al., 2001b). 24 h post-transfection, total cell extracts were analyzed by Western Blotting. The total cell extracts were separated on a 12% strength PA gel, then the proteins were blotted on PVDF membrane. As primary antibodies, the scFvs S18 (C) and N3 (A) (dilution in each case 1:1000) were employed, coupled as a secondary antibody mouse anti-c-myc (1:1000) as a tertiary antibody anti-mouse HRP (horseradish peroxidase). The control used was the anti-LRP antibody mLRP43512 (A), and an anti-mouse IgG-HRP-coupled secondary antibody. As a loading control, the ß-actin level was determined. To this end, an anti-ß-actin antibody (Chemicon) was employed. Detection was carried out by chemiluminescence (Western Lightning, NEN). The svFvS18 and N3 specifically recognize the rec. LRP::FLAG. S18 and N3 recognize endogenous LRP (B,C). N3 recognizes endogenous LR (67 kDa) (B).

Fig. 12. Immunofluorescence analysis of LRP/LR in BHK cells transfected with recombinant SFV RNA. BHK cells were not transfected, as described in Fig. 11, or transfected with the rec. SFV RNAs SFV-1-muLRP-FLAG and SFV-1-huLRP-FLAG. The scFv antibodies S18

and N3 and the W3 antibody known from WO 98/53838 were in each case employed 1:100. For S18 and N3, an Anti-c-myc-FITC-coupled secondary antibody in each case was employed 1:500. For W3, an anti-rabbit Cy2-coupled antibody (1:500) was employed. As a control, only the secondary antibody anti-c-myc FITC (1:500) was employed. The nucleus was stained with DAPI. This staining cannot be seen in the Fig. Cells were fixed using 4% paraformaldehyde. The cells were not permeabilized, which guarantees cell surface staining. The Fig. shows that the scFv S18 and N3 detect LRP::FLAG on the surface of the transfected cells. Both scFv S18 and N3 are also able to detect endogenous LRP (2nd and 3rd left picture from above).

Fig. 13 shows an FACS analysis of BHK cells which were not transfected or were transfected with the recombinant SFV RNAs SFV-1-huLRP-FLAG or SFV-1-muLRP-FLAG. ScFVS18 and N3 were employed in the conc. 18 µg/ml, the W3 antibody and the anti-galectin-3 antibody at 100 µg/ml. Secondary antibody: anti-c-myc FITC-coupled for S18 and N3, anti-rabbit Cy2 for W3 and anti-mouse Cy2-coupled for anti-gal3 antibody (dilution of the secondary antibody 1:500). Cells were not permeabilized, which guarantees cell surface staining. The figure shows that scFv S18 and N3 can detect LRP::FLAG on the cell surface of living cells.

Fig. 14 shows the detection of an increased LR level in the leucocyte fraction of the blood of cattle which are suffering from BSE in the Western Blot by the scFv S18. The blood samples (500 µl) of cattle suffering from BSE and healthy cattle were mixed 1:1 with 1 x SSC, and centrifugation at 4000 rpm/10 min. Removal of the supernatant, resuspend pellet in 1 x SSC, centrifuge again and remove the supernatant. Wash pellet until pellet is white. The white leucocyte pellet is resuspended in 100 µl of TBS. The leucocytes are analyzed on a 12.5% strength PA gel. As a control, GST::LRP from the Baculovirus expression system is applied. The proteins are blotted on a PVDF membrane and with the scFv antibody S18 (1:1000; approximately 2 µg/ml) and, as a control of the detection of the ß-actin level, measured off with an anti-ß-actin antibody (Chemicon). For scFv S18: secondary antibody, anti-c-myc (1:1000), tertiary antibody goat anti-mouse IgG-HRP-coupled (1:5000). GST::LRP was coupled via the W3 antibody, sec. antibody anti-rabbit IgG-HRP. The figure shows an increased LR level in the leucocyte fraction of cattle suffering from BSE.

Fig.15 shows the detection of an increased LR level in the cerebrospinal fluid (CSF) of animals suffering from BSE in comparison with healthy control animals. Identical amounts of protein were applied. As a positive control, GST::LRP (rec. from Baculovirus system) was applied. Total cerebrospinal fluid was separated on a 12.5% strength PA gel and blotted on a PVDF membrane. scFv S18 and N3 in each case diluted 1:1000 (about 2 µg/ml each), secondary antibody mouse anti-c-myc (1:1000), tertiary antibody goat anti-mouse IgG-HRP-coupled. Detection via chemiluminescence. The figure shows an increased LR level detected by scFv S18 and N3 in the CSF of cattle suffering from BSE.

Fig.16 shows schematically that scFv S18 and N3 can prevent the binding and internalization of exogenously tagged PrP^c. The Fig. shows a possible mechanism of action of svFv S18 and N3, namely the blocking of the uptake of the cellular form of the prion protein.

Fig. 17 shows schematically that scFv antibody S18 and N3 added to cells infected with scrapie can cure the cells of a scrapie infection (therapeutic mechanism of action).

Fig. 18 shows schematically a prophylactic mechanism of action of scFv S18 and N3. If both antibodies are added to non-infected cells, they prevent the cells from being infected with scrapie (prophylactic mechanism of action).

Fig. 19 shows schematically the therapeutic in vivo application of the scFv antibodies S18 and N3 in animals (Passive Antibody Transfer). (A) The antibodies are initially injected, preferably intraperitoneally, into healthy animals, preferably hamsters or mice, in order to detect possible specific and nonspecific (i.e. inflammatory response) side effects of the antibodies. (B) The scFv antibodies S18 and N3 are then begun with intraperitoneal administration at various times after a PrPSc inoculation – preferably one day after the PrP^{Sc} inoculation. Furthermore, the antibodies are administered repeatedly according to the following protocol: An initial dose of in each case 200 µg of the S18 and N3 antibodies is injected intraperitoneally (i.p.), preferably into C57/BL6 mice, one day after intraperitoneal inoculation with a prion strain, preferably the BSE strain 6PB1. I.p. injections twice a week with 100 µg of the scFv S18/N3 follow for preferably a further eight weeks. Some of the animals are sacrificed 90 days p.i. and investigated biochemically for PrP^{Sc} presence. The

other animals are either investigated at the terminal stage of a TSE disease or, if no symptoms occurred, at the end of their lifetime.

Fig. 20 shows the gene therapy and cell therapy approach for the treatment of prion diseases with the aid of the scFv antibodies S18 and N3. The gene therapy approach uses viral vectors, preferably AAV, in order to transfer genes which code for S18 and N3 to animals or man. The cell therapy approach is carried out by transplantation of encapsulated cells which secrete the scFv antibodies S18 and N3. Both approaches are explained in greater detail in the following figures.

Fig. 21 shows the use of recombinant AAV viruses which can express scFv S18/N3 on cells infected with scrapie. The infection of neuronal cells infected with scrapie with recombinant S18/N3-expressing AAV viruses should cure these cells of scrapie.

Fig. 22 shows the gene therapy approach with recombinant AAV viruses which express S18/N3 in vivo in mammals (including man), preferably mice. (A) After injection of the recombinant AAV viruses directly into the brain of healthy animals, the expression of the scFV antibodies S18 and N3 is checked by Western Blot analysis of the brain fractions. (B) Mice are injected before, during or after a PrP^{Sc} inoculation with recombinant S18/N3-expressing AAV viruses. A delay in the outbreak of a TSE disease of the mice is determined by psychomotor tests and histological and immunohistochemical analysis of the brain.

Fig. 23 shows the cloning and expression/secretion of scFv antibodies S18 and N3 from neuronal cells and schematically from muscle cells. (A) The cDNA which codes for S18 and N3 is cloned via the restriction sites *Hind*III/*Not*I into the secretion vector pSecTag2B. (B) Neuronal cells are transfected with rec. pSecTag2B, which encodes S18 and N3. (C) 24 hours post-transfection (p.t.), transfected cells show the expression and secretion of S18 and N3 by Western Blotting (1st antibody: anti-c-myc; 2nd antibody: anti-mouse IgG-HRP-conjugated. Detection via chemiluminescence). The figure shows that the scFv S18 and N3 can be secreted from N2a cells.

Fig. 24 shows the administration of S18/N3-secreting ScN2a cells. After transfection of scrapie-propagating cells, these should be cured of PrP^{Sc}.

Fig. 25 shows schematically cell therapy by scFv S18/N3-secreting cells, preferably muscle cells or neuronal cells, BHK cells or NIH3T3 cells, which are encapsulated and are transplanted into the brain of mammals including man. By means of the secretion of scFv S18/N3, the prion propagation in the brain of the organism should be stopped.

Fig. 26 shows the epitope mapping of the scFv S18/N3 antibody.

Fig. 27 shows a schematic representation of the epitope mapping of the scFv S18/N3 antibody.

List of abbreviations:

Ab = antibody
AAV = adeno-associated virus

BHK = baby hamster kidney cells
BSE = bovine spongiform encephalopathy
BSE+ = cow which is suffering from BSE
BSE- = cow which is healthy
CDR1/2/3 = complementary determining region 1/2/3
(s/f/nv) CJD = (sporadic/familial/new variant) Creutzfeldt-Jakob disease

c-myc = epitope from the corresponding oncogene
CMV = cytomegalovirus
CWD = chronic wasting disease
cy2 = 4'-6-diamidine-2-phenylindole
dsRed = red fluorescence protein

eGFP = enhanced green fluorescence protein

ELISA = enzyme linked immunoabsorbent assay

F_{ab} = antigen binding site of an antibody

F_c = constant region of an antibody

FFI = fatal familial insomnia

FITC = fluorescein isothiocyanate

FLAG = polypeptide consisting of the eight amino acids DYKDDDDK

GSS = Gerstmann-Sträussler-Scheinker syndrome

GST = glutathione S-transferase

GST::LRP = fusion of GST (N-terminal) with LRP (C-terminal)

Igκ = κ-chain of the immunglobulin

i.p. = intraperitoneal

Jurkat cells = human, peripheral blood leukemia T cells

N1-47 = scFv antibody selected from the naive scFv bank

His = histidine

HRP = horseradish peroxidase

Linker = amino acid sequence which connects two protein domains

LR = 67 kDa form of the laminin receptor (high affinity laminin receptor)

LRP = laminin receptor precursor

Mr(K) = molecular weight standard in kDa

pIII = phage coat protein

polyHis: polypeptide consisting of six histidine residues

PrP^c = cellular form of the prion protein

PrP^{Sc} = scrapie form of the prion proteins

S1-47 = scFv antibody selected from the synthetic scFv bank

(Sc)GT1 = (scrapie-infected) hypothalamic neuronal cells

(Sc)N2a = (scrapie-infected) neuroblastoma cells

W3 = antibody W3 directed against LRP/LR, polyclonal

scF_v = single chain antibody of the variable region consisting of V_L and V_H connected by a linker

scF_v N3 = single chain antibody N3 selected from the naive scF_v bank

scF_v S18 = single chain antibody S18 selected from the synthetic scF_v bank

SFV = Semliki forest virus

TSE = transmissible spongiform encephalopathy

V_L = light chain of the variable region of an antibody

V_H = heavy chain of the variable region of an antibody

The subject of a first aspect of the present invention is a single-chain antibody molecule, which is directed specifically against LRP/LR and which comprises the amino acid sequence SEQ ID No.2, and homologs or fragments thereof, and homologs of the fragments.

The subject of a further aspect of the present invention is a single-chain antibody molecule, which is directed specifically against LRP/LR and which comprises the amino acid sequence SEQ ID No. 4, and homologs or fragments thereof, and homologs of the fragments.

A homolog of the antibody molecule which comprises the amino acid sequence SEQ ID No. 2 or 4 is customarily homologous to at least 70%, preferably to 80 or 90% and in particular to 95%, to the antibody molecule comprising the amino acid sequence SEQ ID No. 2 or 4 over a region of at least 60, 80 or 100 or more adjacent amino acids.

In general, a fragment of the antibody molecule according to the invention which comprises the amino acid sequence SEQ ID No. 2 or 4, or a homolog thereof, has a sequence length of at least 30, 40, 50 or 60 amino acids.

In a preferred embodiment, the antibody molecule according to the invention is one having the designation S18, which has the amino acid sequence SEQ ID No. 2.

In a further preferred embodiment, the antibody molecule according to the invention is one having the designation N3, which has the amino acid sequence SEQ ID No. 4.

The single-chain antibodies (scFv) according to the invention consist of a fusion of the variable heavy chains (V_H) and the variable light chains (V_L) of an antibody molecule. Both chains are connected via a peptide linker (YOL). scFvs which originate from the scFv libraries

carry a C-terminal histidine tag, which can be used both for the detection of the scFv and for its purification by means of IMAC (Fig. 1 and Fig. 2).

Antibodies against LRP/LR also serve as useful tools for the diagnosis of cancers and can also be employed as therapeutics in cancers. The single-chain antibodies described in the present application, preferably the antibody molecules having the designation S18 and N3, can also be employed for the diagnosis and therapy of cancers.

Fig. 10 shows the cell surface recognition and intracellular recognition of LRP/LR on Jurkat cells (human, peripheral blood leukemia T cells) by the single-chain antibodies S18 and N3. The example shows that the antibody molecules S18 and N3 preferred according to the invention can be suitable for the diagnosis of leukemia. From this finding, S18 and N3 can also be suitable for the diagnosis of other cancers.

Such antibodies are extremely suitable both for the diagnosis and for the therapy of transmissible spongiform encephalopathies (TSE). Therefore the single-chain antibodies described here for the first time are also suitable for the diagnosis of prion diseases.

The antibody molecules preferred according to the invention having the designation S18 or N3 were obtained from complex synthetic and naive antibody banks with the aid of phage-display technology using the GST::LRP fusion protein described in WO 98/53838 as a selection antigen.

The complex scFv banks used for the selection of the scFv antibodies together contained approximately $3x10^9$ individual clones (the naive bank contained approximately 2×10^9 clones, the synthetic bank approximately 1×10^9 clones). The naive IgM bank was generated by the combination of the coding regions for the variable heavy and light chains after PCR amplification of the respective cDNA from spleen or PBLs (peripheral blood lymphocytes). For the production of the synthetic library, human scFv frameworks were selected which are distinguished by good folding and expression properties. The CDR3 sequences of the V_H chain were randomized.

The affinity selection was carried out with each of the two banks on a GST::LRP fusion protein expressed in the Baculovirus system. The production of the GST::LRP fusion protein is described in WO 98/53838.

Fig. 2 schematically summarizes the generation of the 2 x 10^9 different clones for the naive bank. Fig. 3 summarizes the generation of the synthetic scFv antibody bank, which has a complexity of 1 x 10^9 clones.

Fig. 4 schematically summarizes the selection of scFv antibodies for specific binding to GST::LRP.

After the third selection round, crude periplasmatic extracts of 48 individual clones of in each case each bank were tested in the ELISA with respect to the recognition of the recombinant fusion protein GST::LRP (Figs. 5 and 6). 66% of the individual clones in the case of the naive bank and 53% in the case of the synthetic bank showed a positive signal in the ELISA (Fig. 7).

Repeated testing on recombinant GST showed that all antibodies did not recognize GST, although the GST::LRP fusion protein was used as antigen (Fig. 7).

A restriction analysis of the DNAs coding for the scFv with *Bst*NI identified one clone from the naive bank as highly enriched (Fig. 7). The CDR3 sequences of the clones which were enriched from the synthetic bank showed two different consensus sequences. All clones were tested in a Western Blot analysis with respect to the recognition of the recombinant GST::LRP fusion protein (Fig. 8). As a control, GST was added to each track, which showed that none of the clones recognized GST (Fig. 8).

Two clones having the designation N3 (from the naive bank) and S18 (from the synthetic bank) were selected on account of the very strong enrichment for further affinity purification on a Cu^{2+} chelate column.

The single-chain antibody having the designation S18 is encoded at cDNA level from the DNA sequence SEQ ID No. 1.

The DNA is contained in the plasmid pEX/HAM/LRP-S18. The plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 Brunswick under the number DSM 15962 on 10.02.2003. After transformation in E.coli XL1-Blue, the production of the scFv antibody S18 is possible.

The single-chain antibody having the designation S18 shows at protein level the sequence SEQ ID No. 2.

The single-chain antibody having the designation N3 is encoded at cDNA level from the DNA sequence SEQ ID No. 3.

The DNA is contained in the plasmid pEX/HAM/LRP-N3. The plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 Brunswick under the number DSM 15961 on 10.02.2003. After transformation in E.coli XL1-Blue, the production of the scFv antibody N3 is possible.

The antibody having the designation N3 shows at protein level the sequence SEQ ID No. 4.

In a further embodiment according to the present invention, the antibody molecules according to the invention are further modified on one or more positions in order to increase the stability and/or in order to change their biochemical and/or biophysical properties.

The two single-chain antibodies S18 and N3 were tested in various biochemical and cell biology systems with respect to specific LRP/LR recognition.

Murine neuroblastoma cells (N2a) were tested by fluorescence-activated cell scanning (FACS) with the aid of the LRP/LR-specific antibody W3 (polyclonal) from WO 98/53838 and the scFv antibody S18 and N3 for cell surface expression of LRP/LR. N2a cells are the ideal cell system for the propagation of prions. Fig. 9 shows the detection of LRP/LR by the scFv antibodies S18 and N3 on the surface of N2a cells. This shows that both single-chain antibodies S18 and N3 specifically recognize LRP/LR on the surface of N2a cells.

The 37 kDa/67 kDa LRP/LR is strongly expressed on tumor tissue. For example, on the surface of metastasizing tumor cells (Coggin et al., 1999; Rohrer et al., 2001). Fig. 10 shows the detection of the 37 kDa/67 kDa LRP/LR in and on the surface of Jurkat cells with the aid of the scFv antibodies S18 and N3. Jurkat cells are human, peripheral blood leukemia T cells. This demonstrates that the single-chain antibodies described here are able to recognize LRP/LR on tumor cells and shows that the preferred antibodies according to the invention having the designation S18 and N3 are suitable for the diagnosis of cancer.

The scFv antibodies described here having the designation S18 and N3 are able to recognize recombinant human and murine 37 kDa/67 kDa LRP/LR in the fusion with a FLAG tag appended to the carboxy-terminus of LRP in baby hamster kidney cells transfected with recombinant Semliki forest virus RNA by Western Blotting, immunofluorescence and fluorescence-activated cell scanning (FACS). These methods are known to the person skilled in the art in the relevant specialty. Fig. 11 shows the recognition of the murine and human 37 kDa LRP::FLAGs and of the 67 kDa form by the scFv N3 and the recognition of the 37 kDa LRP::FLAG form by the scFv S18 in BHK cells by Western Blotting. Fig. 12 shows surface staining of human and murine LRP/LR-expressing BHK cells with the aid of the scFv antibodies S18 and N3. The polyclonal antibody W3 described in WO 98/53838 is likewise able in this respect. Both scFvs S18 and N3 likewise recognize both murine and human LRP/LR molecules on the surface of transfected BHK cells in the FACS analysis (Fig. 13). The examples shown demonstrate that scFv S18 and N3 recognize LRP/LR molecules highly specifically. The fact that various LRP/LR species of N3 and S18 are recognized is to be attributed to the extremely strong conservation of the protein during evolution (Ardini et al., 1998).

The subject of a further aspect of the present invention are diagnostic compositions which comprise an antibody molecule according to the invention in combination with an acceptable diluent and/or vehicle.

The preferred scFv antibodies according to the invention having the designation S18 and N3 can be employed as diagnostic tools for the recognition of transmissible spongiform

encephalopathies. The antibody molecules having the designation S18 recognize, in the leucocyte fraction of the blood, and the antibody molecules having the designation S18 and N3 recognize, in the cerebrospinal fluid of cattle suffering from BSE, an increased level of the 67 kDa form of the laminin receptor (Fig. 14 and 15). Both scFv antibodies serve as tools for a "surrogate marker test" for the recognition of BSE.

In contrast to the LRP/LR antibody W3 described in WO 98/53838, the single-chain antibodies S18 and N3 preferably used according to the invention are more specific for LR and are distinguished by a higher specificity on account of their monoclonal origin. Furthermore, both scFvs can be produced in unlimited amounts in E. coli, whereas the polyclonal antibody W3 is only available in limited amount.

In a similar manner, the antibody molecules preferably used according to the invention having the designation S18 and N3 can also be used for the diagnosis of TSEs other than BSE, such as scrapie in sheep, chronic wasting disease (CWD) in cervids, nvCJD, sCJD, fCJD, kuru, Gerstmann-Sträussler-Scheinker (GSS) syndrome and fatal familial insomnia (FFI) in man.

The subject of a further aspect of the present invention are pharmaceutical compositions which comprise an antibody molecule according to the invention in combination with a pharmaceutically acceptable diluent and/or vehicle.

The pharmaceutical composition according to the invention are suitable for the therapy of transmissible spongiform encephalopathies (TSEs). TSEs are understood as meaning all known forms of TSEs. The advantage of the antibody molecules according to the invention in comparison with the polyclonal W3 antibody described in WO 98/53838, or other monoclonal murine antibodies of identical specificity, lies in the human origin of the antibody molecules according to the invention and the low immunogenicity associated therewith. scFvs without the F_c part and of human origin are, in consideration of the therapy of patients who are suffering from a TSE, of great advantage because of the potentially lower immunogenicity.

The antibody molecules according to the invention can be employed for the prevention of the binding and internalization of prion proteins to its 37 kDa/67 kDa laminin receptor (see Fig. 16).

Furthermore, the antibody molecules according to the invention can be employed for the treatment of cells infected with scrapie, such as ScGT1, ScN2a and other brain cells which can be infected with scrapie (Fig. 17). Furthermore, the antibody molecules according to the invention can also be employed for prevention (Fig. 18). In this embodiment, they should prevent the outbreak of a prion disease in cell culture.

In a further embodiment, the antibody molecules according to the invention can be employed in vivo in animals in order to cure animals such as rodents (hamsters, mice) of a prion infection or of a transmissible spongiform encephalopathy. Initially, as detailed in Fig. 19, possible side effects of the antibody molecules according to the invention are evaluated by injecting the antibody molecules according to the invention into healthy mice or hamsters. Injection is carried out subcutaneously or directly into the brain. The various possibilities of injection of antibodies in mammals are familiar to the person skilled in the art. Side effects of the antibodies are monitored after certain times post-injection up to the end of the life of the mouse (about 800 days). In a further embodiment such as is shown in Fig. 19, the antibodies according to the invention are injected into the rodents at certain times after inoculation of the rodents with PrP^{Sc}. A possible delay in the outbreak of a TSE or a prevention of a TSE outbreak is observed by the analysis of the dead-time of the PrP^{Sc} accumulation (brain + spleen) and by carrying out psychomotor tests. These methods are known to the person skilled in the art in the relevant specialty.

The subject of a further aspect of the present invention is the use of the antibodies according to the invention in the context of gene therapy and cell therapy (Fig. 20). The gene therapy approach introduces the genes which code for the antibody molecules according to the invention into the organism to be treated. A number of strategies have so far been monitored for gene transfer to neuronal cells using viral vectors (lentiviruses, adenoviruses, adeno-associated viruses (AAV). In this case, the adeno-associated virus (AAV) system was the most promising. AAV is nonpathogenic and can infect nondividing cells such as neurones.

Gene transfer with AAV to the central nervous system (CNS) is efficient and takes place without activation of the cellular or humoral immune response. Gene transfer with AAV was achieved in various animal systems of neurological dysfunction, such as Parkinson's disease (Kirik et al., 2002; Mandel et al., 1997), Alzheimer's disease (Klein et al., 2000), demyelining disease (multiple sclerosis) (Guy et al., 1998), and was also successful for the treatment of brain tumors (Ma et al., 2002).

In a further embodiment, the antibody molecules according to the invention can be expressed in the brain by recombinant AAV viruses. Among the AAV serotypes, AAV2 is the most highly adapted and preferentially transduces neuronal cells. An AAV vector, preferentially an AAV-2 vector which codes for the antibody molecules according to the invention, is used in order to produce high-titre virions according to the method of Grimm (Grimm et al., 1998). 293 cells (human embryonic kidney cell line) are cotransfected with the AAV vector, which codes for an antibody molecule according to the invention, together with an AAV helper plasmid (pDG), which expresses the AAV coat protein genes and further adeno-associated virus genes, which are necessary for helper functions in packaging. Neuronal cells infected with scrapie (ScGT1, ScN2a and further brain cells infected with scrapie) are infected with recombinant AAV viruses, which express the antibody molecules according to the invention, in order to show that the viruses can cure the cells of scrapie (Fig. 21). The recombinant AAV viruses are then injected into the brain of mice, preferably C57Bl6 (Fig. 22). The expression of the antibody molecules according to the invention is checked at various times after the infection by means of Western Blot analysis of the brain fraction (Fig. 22A). Recombinant AAV viruses are injected at various times before and after inoculation with PrP^{Sc} (Fig. 22B). A delay in the outbreak of a TSE disease of the mice is determined by psychomotor tests and histological and immunohistochemical analysis of the brain.

The subject of a further embodiment of the present invention are pharmaceutical compositions which comprise cells producing the antibody molecules according to the invention, the pharmaceutical compositions being suitable to be introduced directly into the brain of mammals. For example, these pharmaceutical compositions can be capsules which contain the antibody-producing cells according to the invention. These compositions are used to treat mammals, including man, which are suffering from a TSE. This strategy implies using

genetically modified cells which are able to secrete a protein, in the present case the antibody molecules according to the invention (Fig. 20). The cells are encapsulated in an immunoprotective polymer, e.g. cellulose sulfate, whose pores allow it to release large molecules, as in the present case antibody. In this process, the cells remain alive over a long period. For a summary of this technique, see also the article by Pelegrin et al., 1998. This strategy has already been employed successfully for the treatment of murine viral diseases (Pelegrin et al., 2000) and human diseases in an animal model such as Parkinson's disease in primates (Date et al., 2000) and Huntington's disease in rats (Emerich et al., 1996).

This process requires the following steps: neuroblastoma cells or other neuronal cells (PC 12) are transiently or stably transfected with an expression vector such as, for example, pSecTag2 (Fig. 23). For secretion, the Ig-κ chain leader sequence is used. For expression in neuronal cells promoters are used, such as CMV (cytomegalovirus). The secretion of the antibodies according to the invention from N2a cells has already been detected (Fig. 23), which demonstrates that the process functions with the antibodies according to the invention. With scrapie-infected neuronal cells, transfection is furthermore carried out using the secretion vectors according to the invention. Owing to the secretion of both antibodies from these cells, the cells can be cured of scrapie (Fig. 24).

For the transplantation of encapsulated cells into the brain of mammals including man for the therapy of TSEs, muscle cells (preferably C2.7 cells) are used, since these are able to secrete antibody over a long period of time if they are transplanted into mice. Myoblasts or differentiated muscle cells (preferably C2.7 cells) are stably transfected with an expression vector which expresses the antibody according to the invention under the control of a muscle cell-specific promoter (Fig. 23). Alternatively, neuronal cells (PC12 cells) or baby hamster kidney (BHK) cells or NIH3T3 cells can also be used, which can secrete the antibodies according to the invention, for further encapsulation and transplantation. The cells expressing the antibody molecules according to the invention are encapsulated in the manner known to the person skilled in the art in the relevant specialty. The process is described in the summary in Pelegrin et al., 1998 (Pelegrin et al., 1998). The material used here can be, for example, cellulose sulfate (Pelegrin et al., 1998).

The encapsulated cells are transplanted into brains of mice in the manner known to the person skilled in the art in this specialty. As in the case of the gene therapy approach described above with AAV viruses, initially the expression of the single-chain antibody is tested. In order to check the therapeutic effect of the antibodies according to the invention against a TSE disease, the experimental animals, preferably mice or hamsters, transplanted with cells expressing the antibody molecules according to the invention are inoculated with PrPSc. A delay in the outbreak of a TSE disease of the mice is determined by psychomotor tests and histological and immunohistochemical analysis of the brain.

The present invention is explained in greater detail below with the aid of nonrestricting examples with reference to the drawings.

Examples

Example 1

Selection of the scFv S18 and N3 from synthetic and naive scFv banks (biopanning)

The antigen used for the selection of single-chain scFv fragments was the GST::LRP fusion protein described in WO 98/53838.

For the selection of the scFv antibodies, two complex scFv banks were used which contained approximately 3 x 10^9 individual clones (the naive bank contained approximately 2 x 10^9 clones, the synthetic bank approximately 1 x 10^9 clones). The naive IgM bank was generated by the combination of the coding regions for the variable heavy and light chains after PCR amplification of the respective cDNA from spleen or PBLs (peripheral blood lymphocytes). For the preparation of the synthetic library, human scFv frameworks were selected which were distinguished by good folding and expression properties. The CDR3 sequences of the V_H chain were randomized.

The selection was carried out with each of the two banks on a GST::LRP fusion protein expressed in the Baculovirus system. The production of the GST::LRP fusion protein is described in WO 98/53838.

Fig. 2 summarizes schematically the generation of the 2 x 10^9 different clones for the naive bank. Fig. 3 summarizes the generation of the synthetic scFv antibody bank, which shows a complexity of 1 x 10^9 clones.

Fig.4 summarizes schematically the selection of scFv antibodies for specific binding to GST::LRP.

After the third selection round, periplasmatic crude extracts of 48 individual clones of in each case each bank were tested in the ELISA with respect to the recognition of the recombinant fusion protein GST::LRP (Figs. 5 and 6). 66% of the individual clones in the case of the naive bank and 53% in the case of the synthetic bank showed a positive signal in the ELISA (Fig. 7).

Repeated testing on recombinant GST showed that all antibodies did not recognize GST, although the antigen used was the GST::LRP fusion protein (Fig. 7).

A restriction analysis of the DNAs coding for the scFv with *Bst*NI showed one clone from the naive bank as highly enriched (Fig. 7). The V_H-CDR3 sequences of the clones isolated from the synthetic bank show two different consensus sequences. All clones were tested in a Western Blot analysis with respect to the recognition of the rec. GST::LRP fusion protein (Fig. 8). The control employed was GST, which showed that none of the clones recognized GST (Fig. 8).

Two clones having the designation N3 (from the naive bank) and S18 (from the synthetic bank) were selected on account of the strongest enrichment for further affinity purification on a Cu^{2+} chelate column.

The single-chain antibody S18 is encoded at cDNA level by the DNA sequence SEQ ID No. 1.

The DNA is contained in the plasmid pEX/HAM/LRP-S18. The plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 Brunswick under the number DSM 15962 on 10.02.2003. After transformation in E.coli XL1-Blue, the production of the scFv antibody S18 is possible.

At protein level, the S18 antibody shows the sequence SEQ ID No. 2.

The single-chain antibody N3 is encoded at cDNA level by the DNA sequence SEQ ID No. 3.

The DNA is contained in the plasmid pEX/HAM/LRP-N3. The plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 Brunswick under the number DSM 15961 on 10.02.2003. After transformation in E.coli XL1-Blue, the production of the scFv antibody N3 is possible.

At protein level, the N3 antibody shows the sequence SEQ ID No. 4.

The person skilled in the art in the relevant specialty can be expressed the scFv antibodies S18 and N3 in a manner known per se by transformation of the plasmids pEX/HAM/LRP-S18 and pEX/HAM/LRP-N3 in E. coli strains such as XL1-Blue in large amounts. The person skilled in the art in the relevant specialty can be purified the expressed proteins S18 and N3 by IMAC (immobilized metal affinity chromatography) in a manner known per se.

Alternatively, the scFv antibodies S18 and N3 can be expressed in the E. coli strain RV308. To this end, the cDNA from the plasmids pEX/HAM/LRP-S18 and pEX/HAM/LRP-N3 coding for S18 and N3 is cloned in the vector pSKK-2 by means of *NcoI*/*Not*I, which led to the expression plasmids pSKK-S-2-18 and pSKK-2-N3.

The expression of the scFv S18 and N3 from pSKK-2 involves the advantage that PIII fusion protein is no longer produced. Moreover, the chaperone SKP is expressed by pSKK-2, which contributes to the improvement of the protein folding. Furthermore, an additional c-myc tag is introduced at the C-terminus, which additionally makes possible alternative detection by

means of an anti-c-myc antibody. The advantage of the RV308 compared with XL1-Blue is its more rapid growth.

For the expression of the scFv antibodies S18 and N3, overnight cultures of E. coli RV308 are transformed with pSKK-S18/N3 (2YT medium containing 100 µg/ml of ampicillin and 50 mM glucose). Dilution of the culture 1:10 in 2YT Medium with 100 µg/ml ampicillin and 50 mM glucose, and culturing until an OD_{600} of 0.6-0.8 is reached follows (26°C, 160 rpm, about 2 h). The culture is centrifuged at 7500 rpm, 20°C, for 20 min. The pellet is resuspended in 1 vol of YTBS with 100 µg/ml of ampicillin, 0.2 mM IPTG. Incubation overnight at 21°C, 160 rpm follows. Centrifugation at 9000 rpm, 4°C, for 20 min then follows. The pellet is resuspended in 1/20 vol with cold TES buffer. Incubation for 1 h on ice with occasional shaking follows. Centrifugation at 9000 rpm, 4°C, for 1 h. The supernatant is dialyzed overnight against PBS (4°C). The dialyzed antibody solution is centrifuged at 9000 rpm, 4°C, for 1 h. The antibodies S18 and N3 are purified by means of IMAC (immobilized metal affinity chromatography). The antibodies S18 and N3 are bound to "chelating sepharose" beads overnight at 4°C. The beads are washed with dialysis buffer at 4°C, and washing of the beads with wash buffer at 4°C follows. The scFvs S18 and N3 are eluted with elution buffer (imidazole) at 4°C. The analysis of the scFv antibodies S18 and N3 on a 12% strength SDS PA gel stained with Coomassie Blue shows bands at a level of approximately 30 kDa. After blotting the bands on a PVDF membrane, it was possible to detect both scFv antibodies by means of anti-c-myc and anti-His antibodies.

The scFv antibodies S18 and N3 thus produced can be employed for further applications in the following examples.

Example 2

Characterization of the scFv antibodies S18 and N3 on cultured cells by FACS, IF and Western Blotting – detection of an increased LRP/LR level on tumor cells (Jurkat cells)

Murine neuroblastoma cells (N2a) were tested for cell surface expression of LRP/LR by fluorescence-activated cell scanning (FACS) with the aid of the LRP/LR specific antibody W3

(polyclonal) from WO 98/53838 and the scFv antibodies S18 and N3 (Fig. 9). N2a cells are the ideal cell system for the propagation of prions. Fig. 9 shows the detection of LRP/LR by the scFv antibodies S18 and N3 on the surface of N2a cells. This shows that both single-chain antibodies S18 and N3 specifically recognize LRP/LR on the surface of N2a cells. Technical details can be inferred from the legend to Fig. 9.

The 37 kDa/67 kDa LRP/LR is strongly expressed on tumor tissue, for example on the surface of the metastasizing tumor cells (Coggin et al., 1999; Rohrer et al., 2001). Fig. 10 shows the detection of the 37 kDa/67 kDa LRP/LR in and on the surface of Jurkat cells with the aid of the scFv antibodies S18 and N3. Jurkat cells are human, peripheral blood leukemia T cells. This demonstrates that the single-chain antibodies described here are able to recognize LRP/LR on tumor cells and shows that the antibodies S18 and N3 are suitable for the diagnosis of cancer. Technical details can be inferred from the legend to Fig. 10.

The scFv antibodies S18 and N3 described here are able to recognize recombinant human and murine 37 kDa/67 kDa LRP/LR in the fusion with a FLAG tag appended to the carboxy terminus of LRP in baby hamster kidney cells transfected with rec. Semliki forest virus RNA by Western Blotting, immunofluorescence and fluorescence-activated cell scanning (FACS). These methods are known to the person skilled in the art in the relevant specialty. Fig. 11 shows the recognition of the murine and human 37 kDa LRP::FLAGs and the 67 kDa form by the scFv N3 and the recognition of the 37 kDa LRP::FLAG form by the scFv S18 in BHK cells by Western Blotting. Fig. 12 shows a surface stain of human and murine LRP/LR-expressing BHK cells with the aid of the scFv antibodies S18 and N3. The polyclonal antibody W3 described in WO 98/53838 is likewise able to do this. Both scFvs S18 and N3 likewise recognize both murine and human LRP/LR molecules on the surface of transfected BHK cells in the FACS analysis (Fig. 13). The examples shown demonstrate that scFv S18 and N3 LRP/LR recognize molecules highly specifically. The fact that the various LRP/LR species of N3 and S18 are recognized is attributed to the extremely strong conservation of the protein during evolution (Ardini et al., 1998).

Technical details can be inferred from the legends to Figures 11, 12 and 13.

Example 3

Application of svFv antibodies S18 and N3 in BSE diagnosis

The scFv antibodies S18 and N3 can are to be employed as diagnostic tools for the recognition of transmissible spongiform encephalopathies. It is demonstrated here that scFv S18 in the leucocyte fraction of the blood and scFv S18 and N3 in the cerebrospinal fluid of cattle suffering from BSE can recognize an increased level of the 67 kDa form of the laminin receptor (Figs. 14 and 15). Both scFv antibodies serve as tools for a "surrogate marker test" for the recognition of BSE. In contrast to the LRP/LR antibody W3 described in WO 98/53838, the single-chain antibodies S18 and N3 are more specific for LR and are distinguished by a higher specificity on account of their monoclonal origin. Furthermore, both scFv can be produced in unlimited amount in E. coli, whereas the polyclonal antibody W3 is only available in limited amount. A great advantage compared with monoclonal antibodies from experimental animals consists in the human origin of the isolated scFv molecules.

Technical details can be inferred from the legends to Figs.14 and 15.

Example 4

Application of svFv antibodies S18 and N3 in TSE therapy

It is claimed that the single-chain antibodies scFv S18 and N3 to be employed for the therapy of transmissible spongiform encephalopathies (TSEs). TSEs are understood as meaning all known forms of TSEs. The advantage of scFv S18 and N3 in comparison with the polyclonal W3 antibody described in WO 98/53838 or other monoclonal murine antibodies of identical specificity lies in the human origin of the scFvs and the low immunogenicity associated therewith. ScFv without an F_c part and of human origin are of great advantage in consideration of the therapy of patients who are suffering from a TSE because of the potentially lower immunogenicity. Moreover, in contrast to W3, the scFvs can be produced in large amount.

scFv S18 and N3 should prevent the binding and internalization of prion proteins to their 37 kDa/67 kDa laminin receptor - as described in Fig. 16.

The scFv S18 and N3 should be employed for the treatment of scrapie-infected cells such as ScGT1, ScN2a and other scrapie-infectable brain cells (Fig. 17). Furthermore, the scFv S18 and N3 antibodies can also be employed for prevention (Fig. 18). In this embodiment, they should also prevent the outbreak of a prion disease in cell culture.

The scFvs S18 and N3 should be employed in vivo in animals in order to cure animals such as rodents (hamsters mice) from a prion infection or a transmissible spongiform encephalopathy. Initially, as detailed in Fig. 19, possible side effects of the ScFv antibodies S18 and N3 are evaluated by injecting the scFv antibodies S18 and N3 into healthy mice or hamsters. Injection is carried out intraperitoneally. The various possibilities of injection of antibodies into mammals are familiar to the person skilled in the art. Side effects of the antibodies are monitored after certain times post-injection up to the end of the life of the mouse (about 800 days). In a further embodiment as shown in Fig. 19, the ScFv antibodies are injected into the rodents intraperitoneally at certain times after an intraperitoneal inoculation of the rodents with PrP^{Sc}. Protocol: An initial dose of in each case 200 µg of the S18 and N3 antibodies is injected intraperitoneally (i.p.) into preferably C57/BL6 mice one day after intraperitoneal inoculation with a prion strain, preferably the BSE strain 6PB1. I.p. injections twice per week with 100 µg of scFv S18/N3 for a further preferably eight weeks follow. Some of the animals are sacrificed 90 days p.i. and investigated biochemically for PrP^{Sc} presence. The other animals are either investigated for the terminal stage of a TSE disease or, if no symptoms occurred, at the end of their lifetime. A possible delay in the outbreak of a TSE or a prevention of a TSE outbreak is observed by the analysis of the times of death, the PrP^{Sc} accumulation (brain + spleen) and by carrying out psychomotor tests. These methods are known to the person skilled in the art in the relevant specialty.

scFv antibodies S18 and N3 should be transferred in vivo by means of gene therapy and cell therapy (Fig. 20). The gene therapy approach introduces the genes which code for the scFvs into the organism to be treated. A number of strategies have so far been monitored for gene transfer to neuronal cells using viral factors (lentiviruses, adenoviruses, adeno-associated

viruses (AAV)). In this case, the adeno-associated-virus (AAV) system was the most promising. AAV is nonpathogenic and can infect nondividing cells such as neurones. Gene transfer with AAV into the central nervous system (CNS) is efficient and takes place without activation of the cellular or humoral immune response. Gene transfer with AAV is achieved in various animal systems of neurological dysfunctions, such as Parkinson's disease (Kirik et al., 2002; Mandel et al., 1997), Alzheimer's disease (Klein et al., 2000), demyelining disease (multiple sclerosis) (Guy et al., 1998), and was also successful for the treatment of brain tumors (Ma et al., 2002).

The scFvs S18 and N3 should be expressed in the brain by rec. AAV viruses. Among the AAV serotypes, AAV2 is the most highly adapted and preferentially transduces neuronal cells. An AAV vector, preferentially an AAV-2 vector, which codes for the scFv S18 or N3, is used in order to produce high-titer virions according to the method of Grimm (Grimm et al., 1998): 293 cells (human embryonic kidney cell line) are cotransfected with the AAV vector, which encodes S18 and N3, together with an AAV helper plasmid (pDG), which expresses the AA coat protein genes and further adeno-associated virus genes, which are necessary for helper functions in packaging. Scrapie-infected neuronal cells (ScGT1, ScN2a and further scrapie-infected brain cells) are infected with recombinant AAV viruses which express scFv S18 and N3 in order to show that the viruses can cure the cells of scrapie (Fig. 21). The recombinant AAV viruses are then injected into the brain of mice, preferably C57Bl6 (Fig. 22). The expression of scFvs S18 and N3 is checked at various times after infection by means of Western Blot analysis of the brain fraction (Fig. 22A). Rec. AAV viruses are injected at different times before and after inoculation with PrPSc (Fig. 22B). A delay in the outbreak of a TSE disease in the mice is determined by psychomotor tests and histological and immunohistochemical analysis of the brain.

scFv antibodies S18 and N3 should be introduced directly into the brain of mammals by transplanting capsules which contain antibody-producing cells. This embodiment likewise serves for treating mammals, including man, which are suffering from a TSE. This strategy implies using genetically modified cells which are able to secrete a protein, in the present case the scFv antibodies S18 and N3 (Fig. 20). The cells are encapsulated in an immunoprotective polymer, e.g. cellulose sulfate, whose pores allow it to release large molecules, as in the

present case antibodies. In this case the cells remain alive for a long time. For a summary of this technique see (Pelegrin et al., 1998). This strategy has already been employed successfully for the treatment of murine viral diseases (Pelegrin et al., 2000) and human diseases in an animal model such as Parkinson's disease in primates (Date et al., 2000) and Huntington's disease in rats (Emerich et al., 1996).

This process necessitates the following steps: Neuroblastoma cells or other neuronal cells (PC 12) are transiently or stably transfected with an expression vector such as, for example, pSecTag2 (Fig. 23). For secretion, the Ig-κ chain leader sequence is used. For expression in neuronal cells promoters are used, such as CMV (cytomegalovirus). The secretion of the antibodies S18 and N3 from N2a cells has already been detected (Fig. 23), which demonstrates that the process works with the scFv antibodies S18 and N3. Scrapie-infected neuronal cells are furthermore transfected with the S18/N3 secretion vectors. By means of the secretion of both antibodies from these cells, the cells can be cured of scrapie (Fig. 24).

For the transplantation of encapsulated cells into the brain of mammals including man for the therapy of TSEs, muscle cells (preferably C2.7 cells) are used, since these are able to secrete antibodies over a long period of time when they are transplanted into mice. Myoblasts or differentiated muscle cells (preferably C2.7 cells) are stably transfected with an expression vector which expresses the scFv antibodies S18 or N3 under the control of a muscle cell-specific promoter (Fig. 23). Alternatively, neuronal cells (PC12 cells) or baby hamster kidney (BHK) cells or NIH3T3 cells which can secrete the antibody S18/N3 can also be used for further encapsulation and transplantation. The scFv S18/N3-expressing cells are encapsulated in the manner known to the person skilled in the art in the relevant specialty. The process is described in summary in Pelegrin et al., 1998 (Pelegrin et al., 1998). The material used here can be, for example, cellulose sulfate (Pelegrin et al., 1998).

The encapsulated cells are transplanted into the brains of mice in the manner known to the person skilled in the art in this specialty. As in the case of the gene therapy approach with AAV viruses described above, the expression of the single-chain antibodies is initially tested. In order to check the therapeutic effect of the scFv antibodies against a TSE disease, the experimental animals transplanted with scFv S18/N3 are preferably mice or hamsters

inoculated with PrPSc. A delay in the outbreak of a TSE disease in the mice is determined by psychomotor tests and histological and immunochemical analysis of the brain.

The person skilled in the art in the relevant specialty is familiar with the techniques for the details in Example 4.

Example 5

Epitope mapping of scFvs S18 and N3

This technique is used to identify the epitopes on LRP which are recognized by the scFvs S18 and N3. To this end, 92 different peptides were synthesized, which in each case had a length of 15 amino acids. The N-terminus of each peptide was displaced by 3 amino acids in relation to the previous peptide, so that each peptide overlapped with the previous peptide by 12 amino acids. The synthesis of the peptides was carried out on a cellulose membrane.

As shown in Fig. 26, three strong signals were detected with the antibody S18. These correspond to the peptides EKAVTKEEFQGEWTA, VTKEEFQGEWTAPAP, and EEFQGEWTAPAPEFT. The common epitope is EEFQGEWTA (AA225-234). This means to the person skilled in the art that the epitope on LRP for the scFv S18 could extend from amino acid 225 to 243 on the laminin receptor. This is illustrated schematically in Fig. 27.

Using the antibody N3, four signals were visualized, as shown in Fig. 26: PSVPIQQFPTEDWSA, PIQQFPTEDWSAAPT, QFPTEDWSAAPTAQA and TEDWSAAPTAQATEW. Here, the common epitope is TEDWSA (AA261-266). This means to the person skilled in the art that the epitope on LRP for the scFv N3 could extend from amino acid 261 to 266 on the laminin receptor (cf. Fig. 27).

The techniques for the details in Example 5, which are familiar to the person skilled in the art in the relevant specialty, are explained below in detail.

The antibody binding test was carried out similarly to Western Blots for the detection of LRP by the antibodies scFv S18 and N3 (Cf. Fig. 11). In this case, the membrane bound with 92 peptides was incubated with the scFv antibodies S18 and N3 (dilution 1:5000). In order to

remove an antibody (S18) (in order to detect with the second antibody (N3)), the membrane was incubated 3 times at 60°C for 20 minutes with "stripping" buffer (8 M urea, 0.5% β-mercaptoethanol).

5

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Single chain antibodies against the 37 kDa/67 kDa laminin receptor as tools for the diagnosis and therapy of prion diseases, production and use

Number of sequences: 4

Computer-readable version:
(A) Media: CD
(B) Computer: IBM PC compatible
(C) Operating system: PC-DOS/MS-DOS
(D) Software: WinWord 6.0

(2) INFORMATION FOR SEQ ID No. 1
(i)SEQUENCE CHARACTERISTICS:
(A) Length: 816 base pairs

(B) Type: nucleic acid

(C) Strandedness: double-stranded

(D) Topology: linear

(ii) MOLECULE TYPE: nucleic acid

(A) Description: DNA codes for single chain antibody scFv S18. The DNA is contained in the plasmid pEX/HAM/LRP-S18. This plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 under the accession number xxxx. After transformation of the plasmid in E. coli XL1 Blue, the production of the scFv antibody S18 is possible.

(iii) Hypothetical: no

(iv) Antisense: no

(xi) SEQUENCE DESCRIPTION: SEQ ID No. 1:

5' CAGG TGCAGCTGCA GGAGTCTGGG GGAGGCTTGG TACAGCCTGG
GGGGTCCCTG AGACTCTCCT GTGCAGCCTC TGGATTCATG TTTAGCAGGT
ATGCCATGAG CTGGGTCCGC CAGGCTCCAG GGAAGGGGCC AGAGTGGGTC
TCAGGTATTA GTGGTAGTGG TGGTAGTACA TACTACGCAG ACTCCGTGAA
GGGCCGGTTC ACCGTCTCCA GAGACAATTC CAAGAACACG CTGTATCTGC
AAATGAACAG CCTGAGAGCC GAGGACACGG CCGTATATTA CTGTGCGAGA
CATCCGGGTT TTTGGCATTT TGACTACTGG GGCCAGGGAA CTCTGGTCAC
CGTCTCCTCA GGGAGTGCAT CCGCCCCAAA GCTTGAAGAA GGTGAATTTT
CAGAAGCACG CGTATCTGAA CTGACTCAGG ACCCTGCTGT GTCTGTGGCC
TTGGGACAGA CAGTCAGGAT CACATGCCAA GGAGACAGCC TCAGAAACTT
TTATGCAAGC TGGTACCAGC AGAAGCCAGG ACAGGCCCCT ACTCTTGTCA
TCTATGGTTT AAGTAAAAGG CCCTCAGGGA TCCCAGACCG ATTCTCTGCC
TCCAGCTCAG GAAACACAGC TTCCTTGACC ATCACTGGGG CTCAGGCGGA
AGATGAGGCT GACTATTACT GTAACTCCCG GGACAGAAGT GGTAATCATG
TAAATGTGCT ATTCGGCGGA GGGACCAAGC TGACCGTCCT ACGTCAGCCC

AAGGCTGCCC CCTCGGTCAC TCTGTTCCCG CCCTCTTCTG CGGCCGCTGG ATCCCATCAC CATCACCATC AC 3'

(2) INFORMATION FOR SEQ ID No. 2

(i)SEQUENCE CHARACTERISTICS:
Length: 268 amino acids
Type: protein
Strandedness: single-stranded
Topology: linear

MOLECULE TYPE: protein
(A) Description: This protein corresponds to the single chain antibody S18. It can be synthesized in E. coli XL1 Blue after the transformation of the plasmid pEX/HAM/LRP-S18 .

Hypothetical: no

Antisense: no

(xi) SEQUENCE DESCRIPTION: SEQ ID No. 2:
amino-terminus QVQLQESG GGLVQPGGSL RLSCAASGFM FSRYAMSWVR QAPGKGPEWV SGISGSGGST YYADSVKGRF TVSRDNSKNT LYLQMNSLRA EDTAVYYCAR HPGFWHFDYW GQGTLVTVSS GSASAPKLEE GEFSEARVSE LTQDPAVSVA LGQTVRITCQ GDSLRNFYAS WYQQKPGQAP TLVIYGLSKR PSGIPDRFSA SSSGNTASLT ITGAQAEDEA DYYCNSRDRS GNHVNVLFGG GTKLTVLRQP KAAPSVTLFP PSSAAAGSHH HHHH carboxy-terminus

(2) INFORMATION FOR SEQ ID No. 3
(i)SEQUENCE CHARACTERISTICS:

(A) Length: 834 base pairs

(B) Type: nucleic acid

(C) Strandedness: double-stranded

(D) Topology: linear

(ii) MOLECULE TYPE: nucleic acid

(A) Description: DNA codes for single chain antibody scFv N3. The DNA is contained in the plasmid pEX/HAM/LRP-N3. This plasmid was deposited in the DSMZ, Mascheroder Weg 1b, D-38124 under the accession number xxxx. After transformation of the plasmid in E. coli XL1 Blue, the production of the scFv antibody N3 is possible.

(iii) Hypothetical: no

(iv) Antisense: no

(xi) SEQUENCE DESCRIPTION: SEQ ID No:3:

5' GAAG TGCAGCTGGT GGAGTCTGGG GGAGGCGTGG TCCAGCCTGG
GAGGTCCCTG AGACTCTCCT GTGCAGCGTC TGGATTCACC TTCAGTAGCT
ATGGCATGCA CTGGGTCCGC CAGGCTCCAG GCAAGGGGCT GGAGTGGGTG
GCAGTTATAT GGTATGATGG AAGTAATAAA TACTATGCAG ACTCCGTGAA
GGGCCGATTC ACCATCTCCA GAGACAATTC CAAGAACACG CTGTATCTGC
AAATGAACAG CCTGAGAGCC GAGGACACGG CTGTGTATTA CTGTGCGACT
ATACCGCGCT CGTCTTTCTA CTACGGTATG GACGTCTGGG GCCAAGGGAC
CACGGTCACC GTCTCCTCAG GGAGTGCATC CGCCCCAACC CTTAAGCTTG
AAGAAGGTGA ATTTTCAGAA GCACGCGTAC AGCCTGTGCT GACTCAGCCA
CCCTCAGCGT CTGGGACCCC AGGGCAGAGG GTCACCATCT CTTGTTCTGG
AAGCAGATCC AACATCGGAA GTAATACTGT AAACTGGTAC CAGCAGCTCC
CAGGAACGGC CCCCAAACTC CTCATCTATG GTAATAATCA GCGGCCCTCA
GGGGTCCCTG AGCGATTCTC TGGCTCCAAG TCTGGCACCT CAGCCTCCCT
GGCCATCAGT GGGCTCCAGT CAGAGGATGA GGCTGATTAT TACTGTGCAG
CGTGGGATGA CAGCCTGACT GGTGTGCTTT TCGGCGGAGG GACCAAGCTG

ACCGTCCTAG GTCAGCCCAA GGCTGCCCCC TCGGTCACTC TGTTCCCGCC CTCTTCTGCG GCCGCTGGAT CCCATCACCA TCACCATCAC 3'

(2) INFORMATION FOR SEQ ID No. 4

(i)SEQUENCE CHARACTERISTICS:

Length: 278 amino acids

Type: protein

Strandedness: single-stranded

Topology: linear

MOLECULE TYPE: protein

(A) Description: This protein corresponds to the single chain antibody N3. It can be synthesized in E.coli XL1 Blue after the transformation of the plasmid pEX/HAM/LRP-N3.

Hypothetical: no

(iv) Antisense: no

(xi) SEQUENCE DESCRIPTION: SEQ ID No. 4:

amino-terminus EVQLVESGGG VVQPGRSLRL SCAASGFTFS SYGMHWVRQA PGKGLEWVAV IWYDGSNKYY ADSVKGRFTI SRDNSKNTLY LQMNSLRAED TAVYYCATIP RSSFYYGMDV WGQGTTVTVS SGSASAPTLK LEEGEFSEAR VQPVLTQPPS ASGTPGQRVT ISCSGSRSNI GSNTVNWYQQ LPGTAPKLLI YGNNQRPSGV PERFSGSKSG TSASLAISGL QSEDEADYYC AAWDDSLTGV LFGGGTKLTV LGQPKAAPSV TLFPPSSAAA GSHHHHHH carboxy-terminus